# Effects of Iron Conduits On Line Drop


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1905

# AN INVESTIGATION OF THE EFFECTS OF IRON CONDUITS ON LINE DROP.



A THESIS PRESENTED

BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE

OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED

COURSE OF STUDY

IN

ELECTRICAL ENGINEERING.



CHICAGO, JUNE ,6th. 1905.

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# AN INVESTIGATION OF THE EFFECTS OF IRON CONDUITS ON LINE DROP.

The tendency in central station practice has been to decrease the cost of generation of energy ,and to cut down the losses wherever it was possible so that at the present time the attention has been directed to the investigation of and diminishing , of any loss which decreases the effeciency and output of the central station. Inlarge central stations a loss or leake of energy amounting to only a fraction of one per cent of the total power developed , will in the course of a year mean a loss of hundreds and sometimes thousands of dollars to the company.
This fact has led to the investigation of losses in the transmission of energy , and in connection with this the effect of iron conduit on line drop when the iron conduit is used in alternating current work.

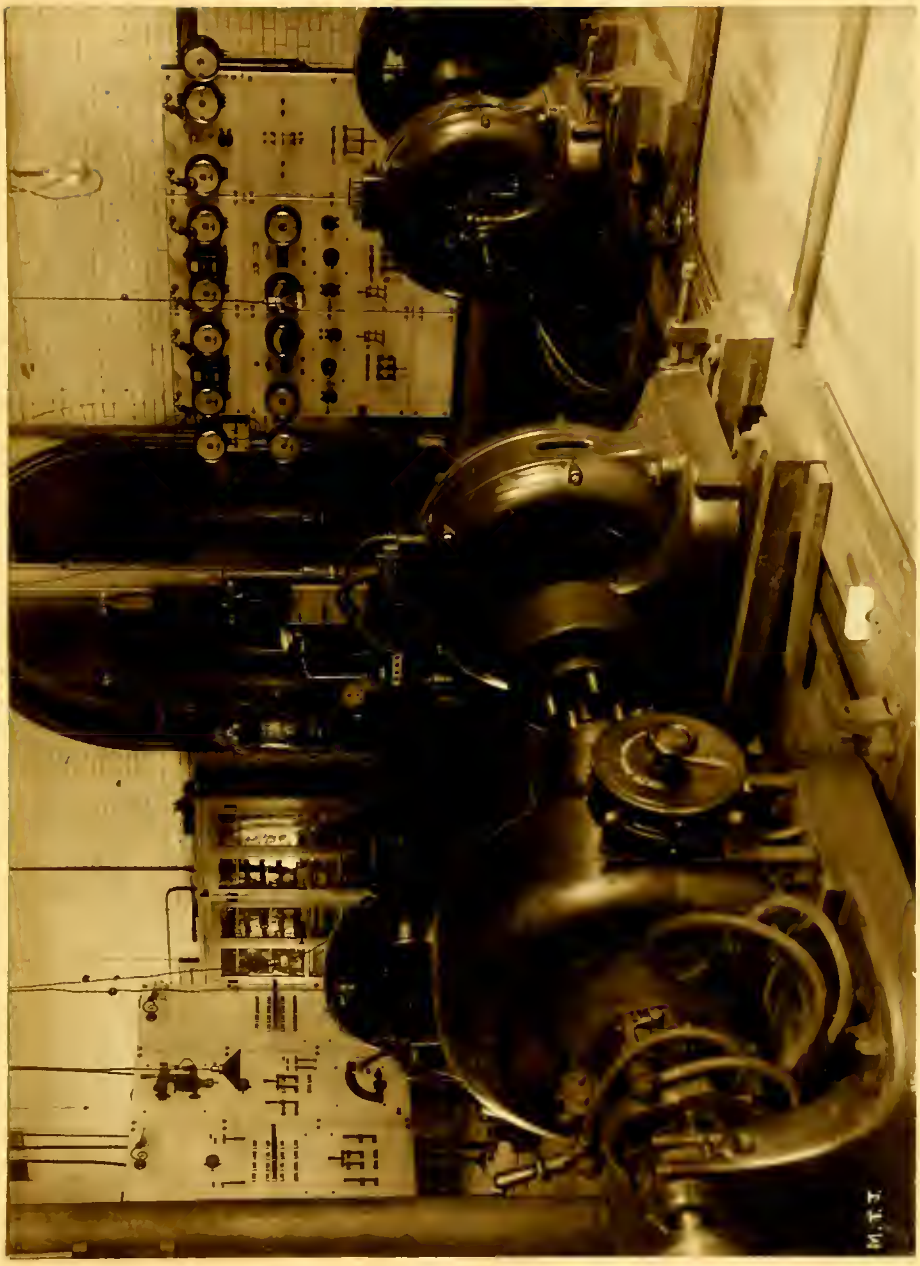
It is current practice in central stations to place the leads from the generators, rotary converters , and transformers to the switchboard in iron conduits. This is also true of substation wiring as well as of the wiring in large buildings.

It is the object of this paper to investigate and discuss the effect of the iron conduit on the line drop and experimentally determine the magnitude of the losses due to it.

It is a well known fact that when direct current is used the iron pipe or conduit would have no effect on the line drop and th e only difference of potential would be caused by the ohmic resistance of the wire. When alternating current is used there maybe a noticeable drop due to the self-induction of the wire.

One of the fundamental principles of electricity is that when a conductor carries an electric current there is a field set up around that conductor proportional to the current. Any change in this field will produce a counter electromotive force in the conductor proportional to the rate of change of the flux. This counter- electromotive force acts as a resistance opposing the flow of the current in the conductor. When the conductor is enclosed in the iron conduit the flux is increased due to the increased permeability of the iron over air; thereby increasing the counter- electromotive force and thus causing a larger drop over the wire.

Experiments along this line were carried on with single and three phase currents under different conditions of load, variation of frequency , and conduits.



## Description of The Apparatus Used.

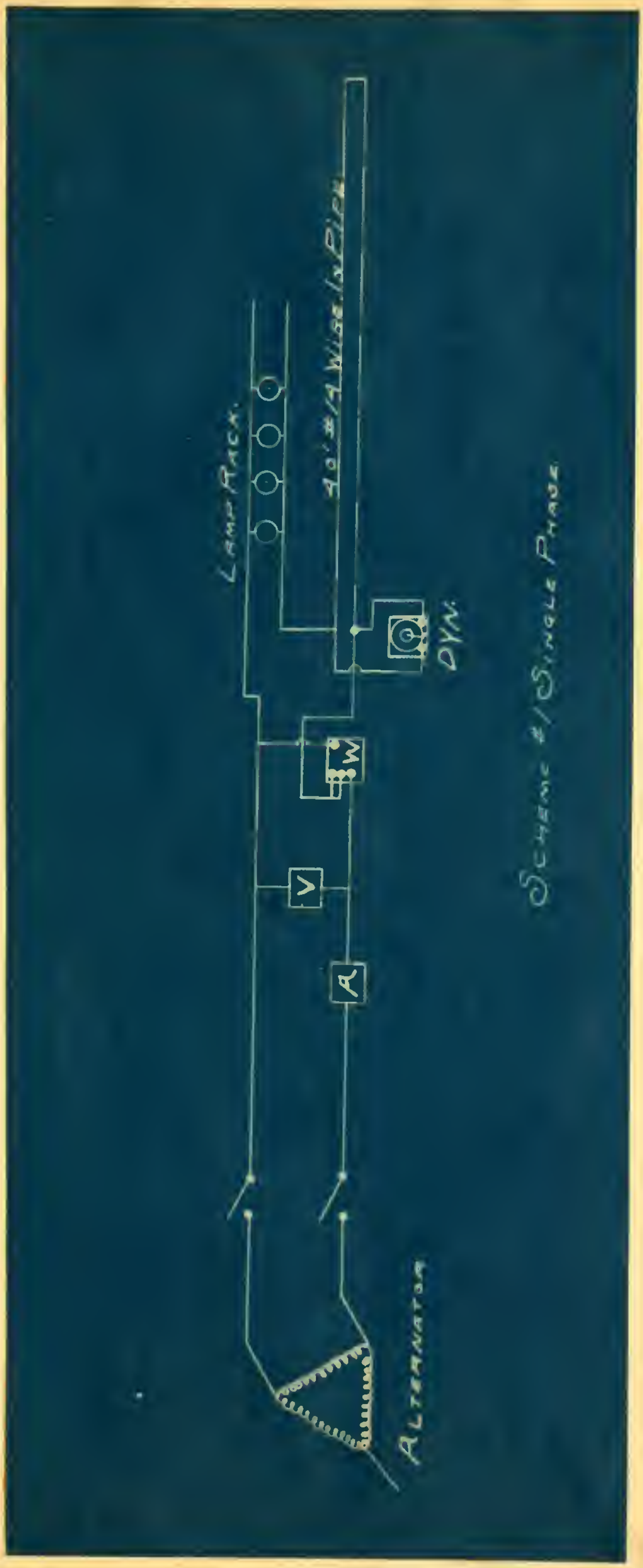
The following machines and instruments were used in obtaining the data for this paper. The alternating current both single and three-phase , for fifty(50) , fifty-five (55) , and sixty (60) cycles was obtained from a General Electric Company three-phase alternating current generator # 65447- six pole -- giving seventy-two (72) amperesat twelve hundred (I200) revolutions per minute and onehundred and twenty (I20) volts at full load. The alternator was driven by a direct - connected Chocker- Wheeler motor # 265 rated for twenty - six (26) horse power at one thousand twenty-five revolutions per minute ; taking one hundred and ninty (I90) amperes at one hundred and fifteen (II5) volts. The generator was excited by current from a Westinghouse compound direct current generator # 208697 rated at one hundred and twenty-five (I25) volts -- one hundredand twenty (I20) amperes at one thousand fifty (I050) revolutions per minute, driven a direct - connected twenty-six (26) horse power Crocker- Wheeler motor. This method of excitation afforded good regulation for all condition of load and frequency.

For all data at twenty-five and thirty cycles, single and three-phase currents was taken on a direct-driven Wood alternator rated at thirty horse power , one hundred and ten (IIO) volts and five hundred (500) revolutions per minute.

The load was obtained by means of an incandescent lamp rack and so assured a non-inductive load .

Thomson alternating current ammeters and voltmeters calibrated for this experiment were used to measure the current and pressure respectively. A Weston wattmeter was used to measure the power consumed and a Queen electro-dynamometer calibrated to read in volts was used to measure the drop over the wire in the pipes.

The different frequencies were obtained by running the alternators at different speeds . A Weston tachometerwas used to indicate the speed.


LAMP RACK.
40' #14 WIRE IN PIPE
DYN.
W
V
A
ALTERNATOR
SCHEME #1 SINGLE PHASE

Single-Phase.

Method:-

The authors first investigated the drop over the wire in the conduit when single phase current was used. The apparatus was connected as shown in the scheme (#I)on the preceeding page. The lamp rack used for the load was connected in series with the wire in the pipe, and an ammeter and the series coil of the wattmeter . The voltmeter was connected across the line , reading the drop over the wire in the pipes, and the lamp rack.The pressure coil of the wattmeter was connected to the same points as the voltmeter.

The electrodynamometer was connected to read the drop over thee wire in the pipe . Eighty feet of(# I4) number fourteen rubber covered copper wire was used being doubled in forty feet of one and one eighth inch iron conduit.

Runs were taken with the wire in thee pipe for twenty-five , thirty, fifty , fifty-five, and sixty cycles. The voltage was maintained constant at one hundred and ten (IIO) volts over the lamps. Simultaneous readings were take n of the drop over the wire in the pipe by means of the dynamometer and watts consumed in the circuit, by the wattmeter for loads varying from ten to fifty amperes by five ampere steps. The wire was then removed from the iron conduit and similiar readings taken for the same frequencies and loads.

Single-phase Data. Wire in the Pipe.

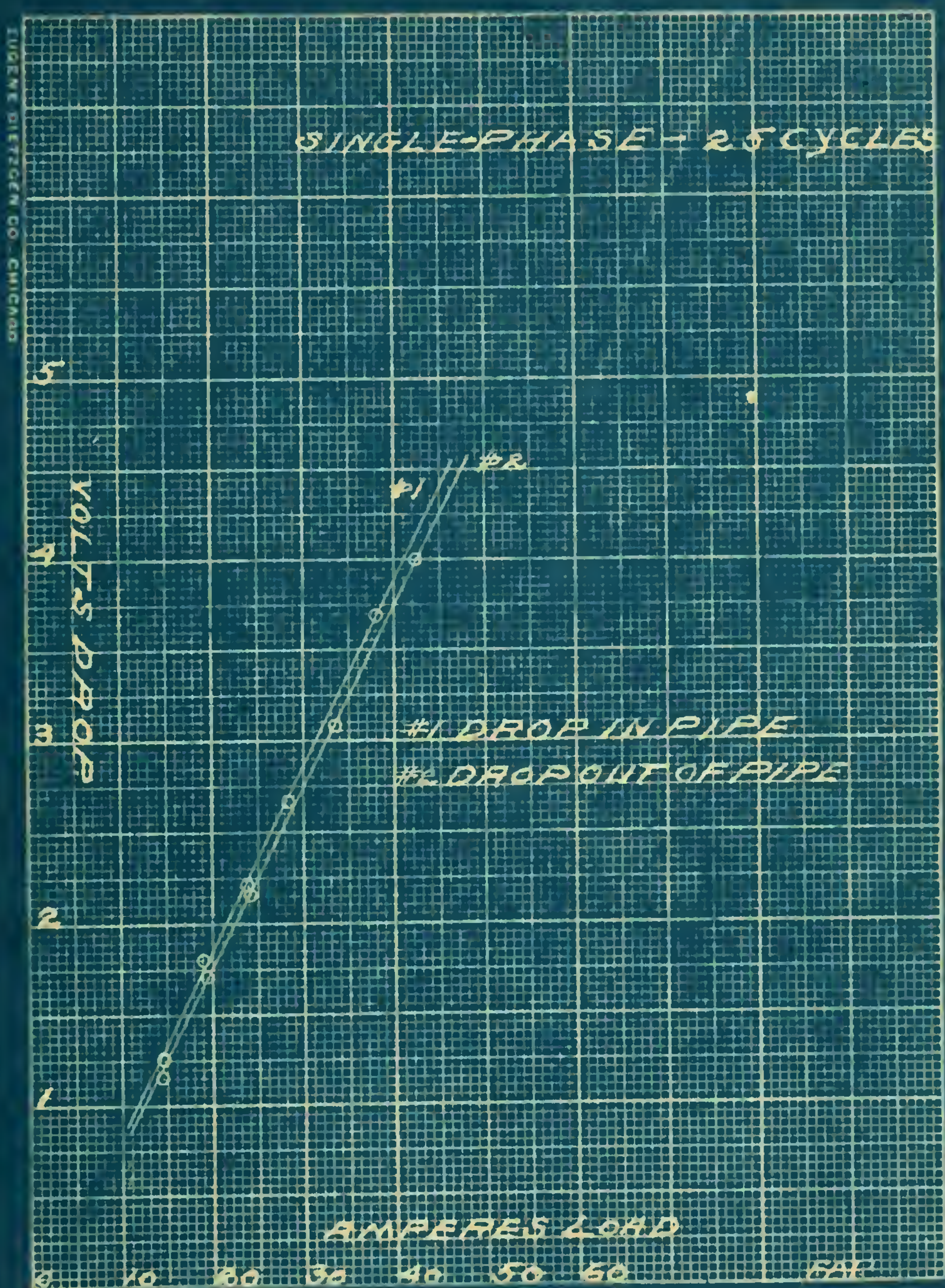
| 60 cycles. | | | 55 cycles. | | | 50 cycles. | | |
|---|---|---|---|---|---|---|---|---|
| Amp. | K.W. | Volts. | Amp. | K.W. | Volts. | Amp. | K.W. | Volts. |
| II.5. | I.I | .8 | II.5 | I.I | .8 | I0.4 | I.I | .67 |
| I5.5 | I.6 | I.32 | I5.5 | I.6 | I.32 | I4.5 | I.6 | I.3 |
| I9.5 | 2.2 | I.8 | I8.5 | 2.I | I.7 | I8.4 | 2.I | I.74 |
| 24. | 2.6 | 2.2 | 22.3 | 2.62 | 2.I4 | 23. | 2.6 | 3.2 |
| 29. | 3.2 | 2.72 | 28. | 3.2 | 2.6 | 27.4 | 3.I5 | 2.6 |
| 33. | 3.6 | 3.I5 | 32. | 3.7 | 3. | 32. | 3.7 | 3.03 |
| 37.5 | 4.25 | 3.65 | 36.2 | 4.2 | 3.5 | 36.5 | 4.2 | 3.5 |
| 4I.5 | 4.8 | 4.I5 | 40.5 | 4.75 | 3.95 | 40.5 | 4.75 | 3.98 |
| 46. | 5.2 | 4.55 | 45. | 5.25 | 4.5 | 45. | 5.2 | 4.48 |
| 48.5 | 5.5 | 4.9 | 49 | 5.72 | 4.9 | 49. | 5.7 | 4.87 |

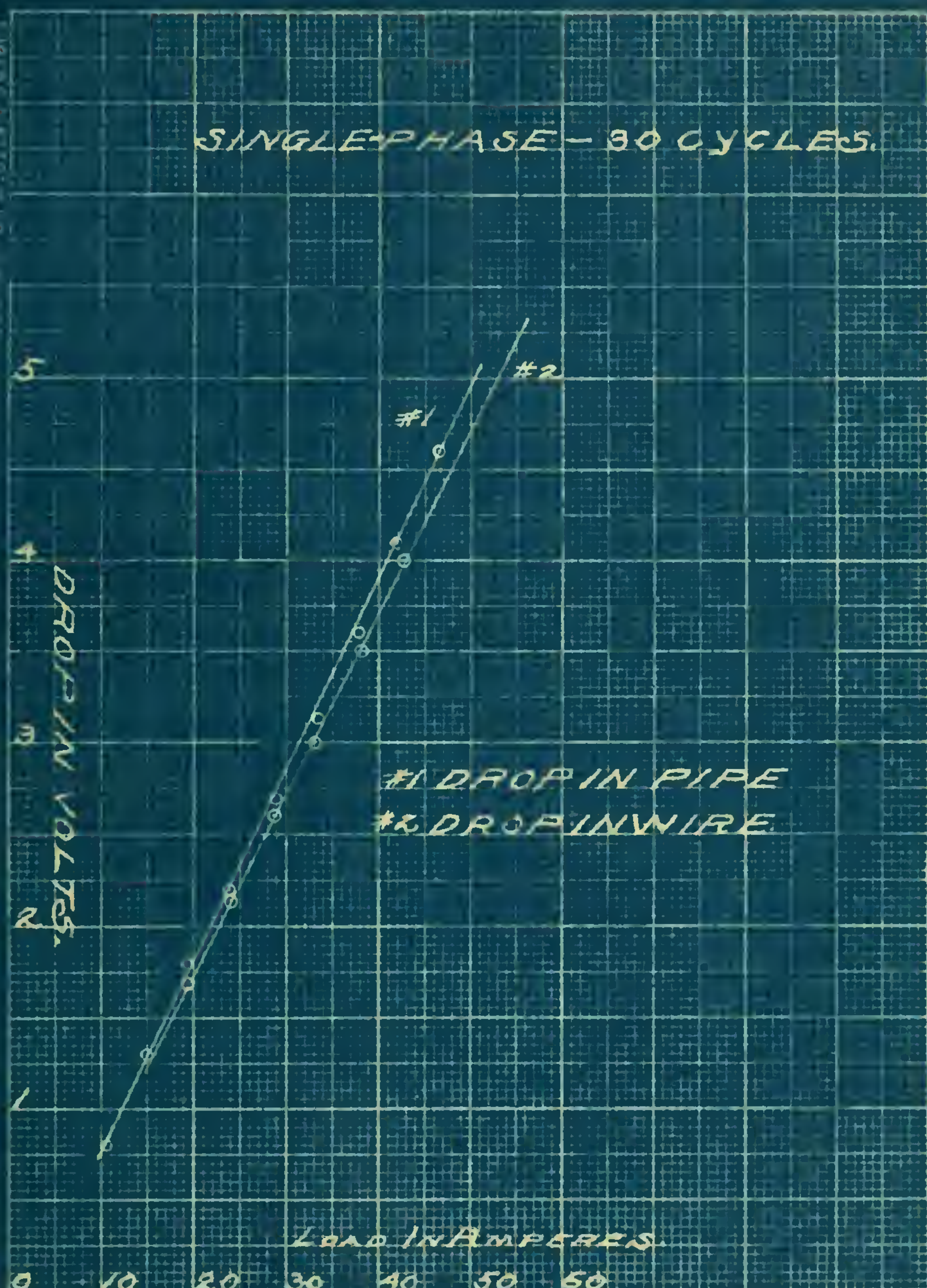
| 30 cycles. | | | 25 cycles. | | |
|---|---|---|---|---|---|
| Amp. | K.W.. | Volts. | Amp. | K.W. | Volts. |
| I0.5 | I. | .8 | I0.5 | I. | .66 |
| I5. | I.5 | I.3 | I4.8 | I.5 | I.25 |
| I9.2 | 2.08 | I.8 | I9. | 2.I | I.8 |
| 24. | 2.6 | 2.2 | 24. | 2.62 | 2.2 |
| 29. | 3.I4 | 2.7 | 28.8 | 3.I8 | 2.65 |
| 33.4 | 3.72 | 3.I4 | 34. | 3.63 | 3.I |
| 38. | 4.22 | 3.6 | 38. | 4.2 | 3.7 |
| 42. | 4.73 | 4.I | | | |
| 46.5 | 5.28 | 4.6 | | | |

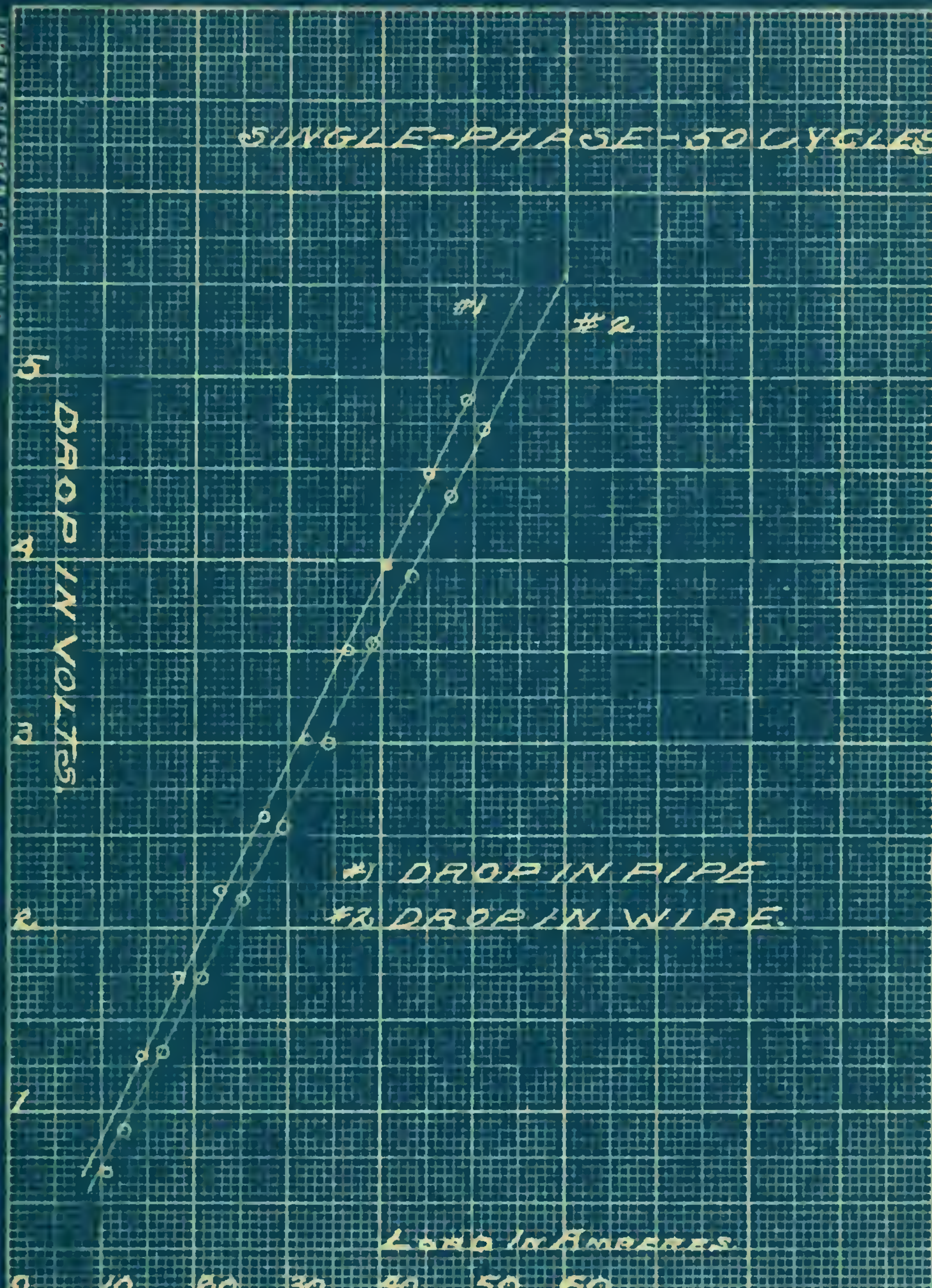
.Single- phase Data . Wire out of Pipe.

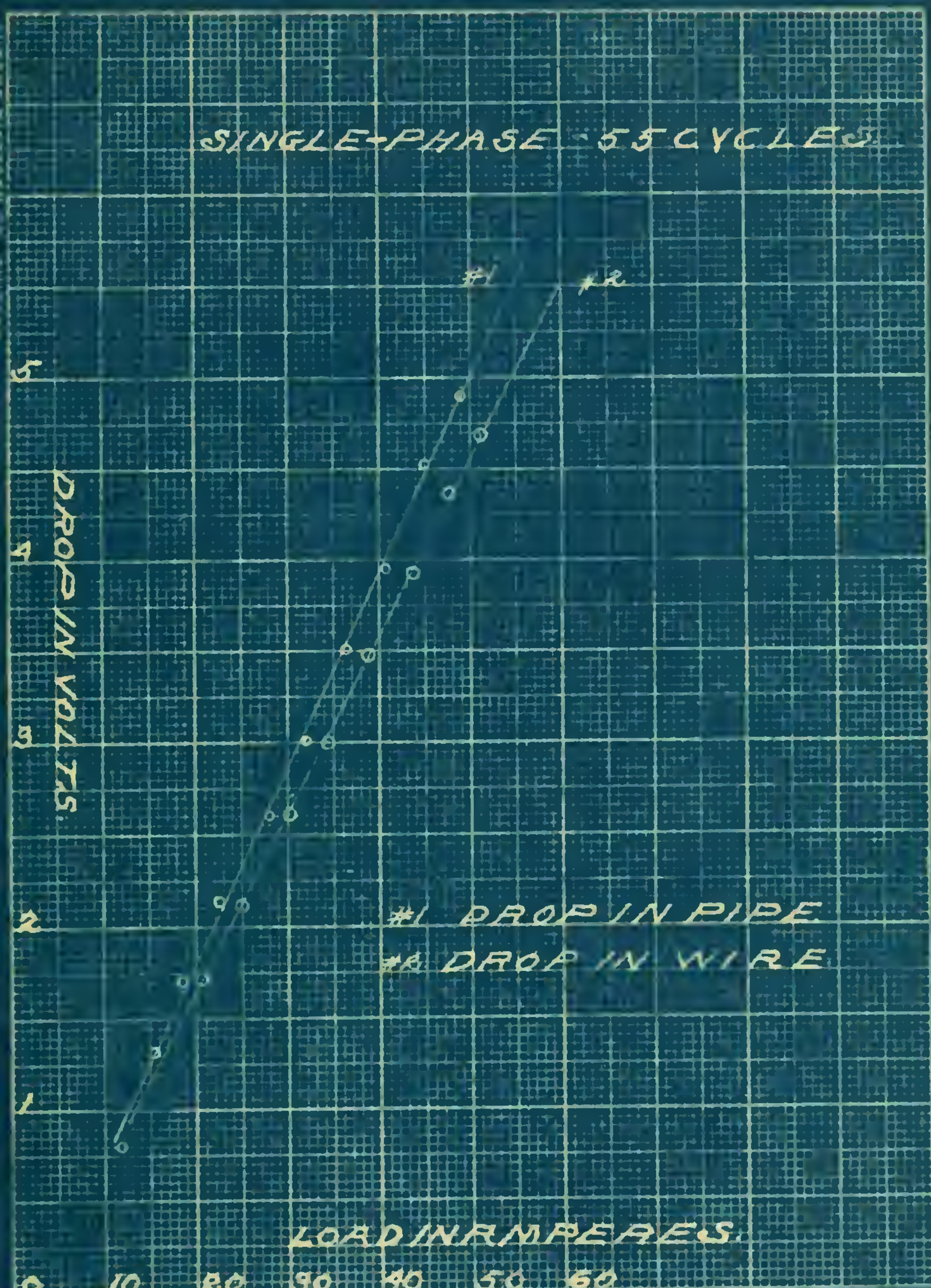
| 60 cycles. | | | 55 cycles. | | | 50 cycles. | | |
|---|---|---|---|---|---|---|---|---|
| Amp. | K.W. | Volts. | Amp. | K.W. | Volts. | Amp. | K .W. | Volts. |
| I0.5 | I.I | .5 | I2.5 | I.2 | .64 | I2.5 | I. | .9 |
| I4.8 | I.52 | I.2 | I6.5 | I.5 | I.3 | I6.5 | I.55 | I.34 |
| I9. | 2.05 | I.64 | 20.8 | 2.05 | I.74 | 20.7 | 2.I | I.73 |
| 24. | 2.62 | 2.I | 25. | 2.6 | 2.I2 | 25. | 2.6 | 2.I5 |
| 29. | 3.2 | 2.55 | 30. | 3.I5 | 2.6 | 30. | 3.I3 | 2.54 |
| 33. | 3.7 | 2.94 | 34.2 | 3.65 | 3. | 34.2 | 3.68 | 3. |
| 37.5 | 4.2 | 3.4 | 38.8 | 4.I5 | 3.47 | 39. | 4.2I | 3.55 |
| 42.4 | 4.6 | 3.84 | 43.5 | 4.66 | 3.9 | 43.2 | 4.7 | 3.9 |
| 47. | 5.I | 4.4 | 47:5 | 5.I7 | 4.39 | 47.5 | 5.2 | 4.35 |
| 5I. | 5.6 | 4.78 | 5I. | 5.62 | 4.7 | 5I. | 5.6 | 4.73 |

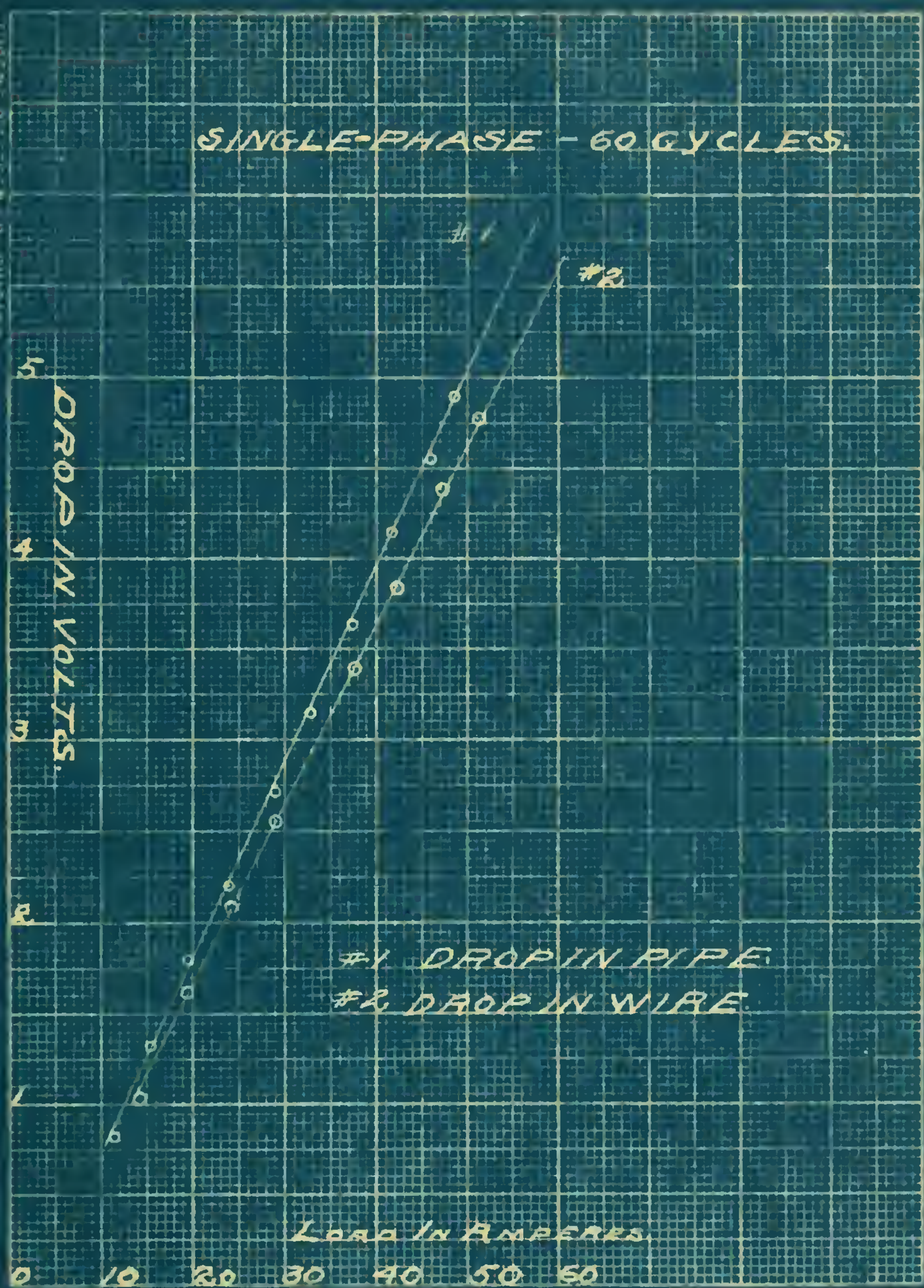
| 30 cycles. | | | 25 cycles. | | |
|---|---|---|---|---|---|
| Amp. | K . W . | Volts. | Amp. | K . W . | Volts. |
| I0.5 | I.62 | .62 | I0.5 | I.I | .56 |
| I4.6 | I.5 | I.3 | I4.6 | I.5 | I.25 |
| I9.2 | 2.08 | I.7 | I9.2 | 2.I | I.72 |
| 24. | 2.62 | 2.I5 | 24. | 2.63 | 2.I8 |
| 28.8 | 3.I8 | 2.6 | 28.7 | 3.2 | 2.65 |
| 33. | 3.7 | 3. | 33.2 | 3.7 | 3.07 |
| 38. | 4.23 | 3.5 | 37.6 | 4.2 | 3.58 |
| 42.4 | 4.8 | 4. | 42.5 | 4.8 | 4. |
| 46.8 | 5.3 | 4.5 | | | |

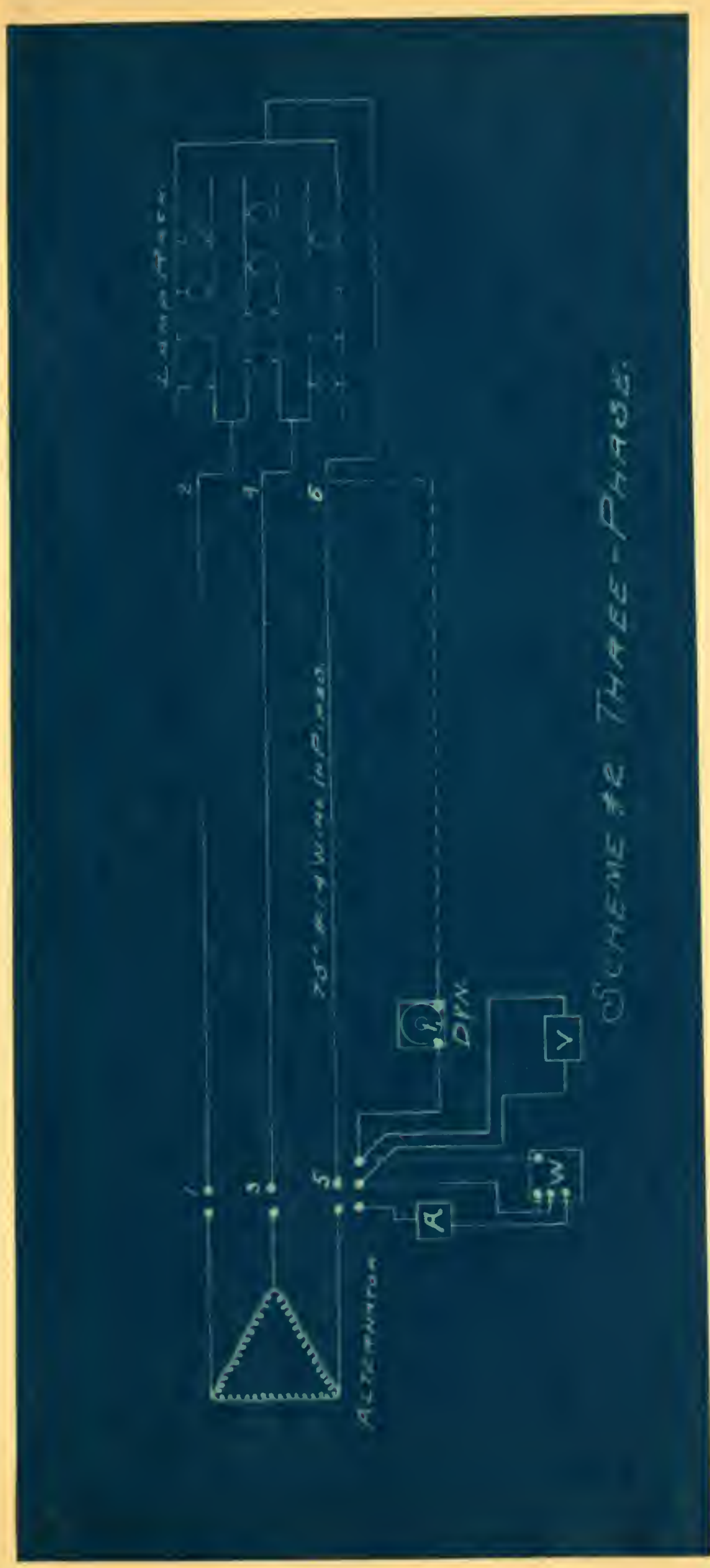

SINGLE-PHASE - 25 CYCLES
VOLTS DROP
#1
#2
#1 DROP IN PIPE
#2 DROP OUT OF PIPE
AMPERES LOAD
0 10 20 30 40 50 60
1 2 3 4 5
EUGENE DIETZGEN CO. CHICAGO


SINGLE-PHASE — 30 CYCLES.
#1
#2
#1 DROP IN PIPE
#2 DROP IN WIRE
DROP IN VOLTS.
LOAD IN AMPERES.
0
10
20
30
40
50
60
1
2
3
4
5


SINGLE-PHASE-50 CYCLES
#1
#2
DROP IN VOLTS.
#1 DROP IN PIPE
#2 DROP IN WIRE.
LOAD IN AMPERES.
0
1
2
3
4
5
10
20
30
40
50
60
EUGENE DIETZGEN CO. CHICAGO


SINGLE-PHASE 55 CYCLES
#1
#2
DROP IN VOLTS.
5
4
3
2
1
#1 DROP IN PIPE
#2 DROP IN WIRE
LOAD IN AMPERES.
0
10
20
30
40
50
60


SINGLE-PHASE - 60 CYCLES.
#1
#2
DROP IN VOLTS.
5
4
3
2
1
#1 DROP IN PIPE
#2 DROP IN WIRE
LOAD IN AMPERES.
0
10
20
30
40
50
60


LAMP RACK.
75' #14 WIRE IN PIPES.
1
2
3
4
5
6
ALTERNATOR
A
W
V
DYN.
SCHEME #2 THREE-PHASE.

Three- Phase.

Method:-

Determination of the drop in the pipe when three wires ansd three-phase currents were used with balanced load.

The apparatus used for the determination of the above was connected as shown in scheme #2 given on the preceeding page. Three leads of number fourteen rubber- covered copper wire each seventy-five feet long were placed in seventy-five feet of one and one eighth inch conduit. These are represented in th scheme as extending from points I-2; 3-4; and from 5-6 respecti ively. Points 1-3-5- represent a universal switch by means of which the ammeter and wattmeter could be placed in series with any one of the lines.

There were two pressure terminals on this switch. One of these pressure terminals was connected in series with a sliding contact which could be rotated , making contact with either of the other phases as was desired. A delta connection w used on the lamp racks as shown in the scheme.

Care was taken to keep the load balanced , one bank of lamps on each rack being placed in the circuit for each reading. The pressure over each phase was maintained constant at one hundred and ten (II0) volts and loads of from ten to fifty-five amperes were used.

Simultaneous readings of ammeter, voltmeter, and electro-dynamometer were taken for each load with the wires in the pipe and at the different frequencies.

The wires were then taken from the pipe and the experimenT repeated , readings being taken with the different loads and frequencies as before.

Three-phase . Wire in the pipes.

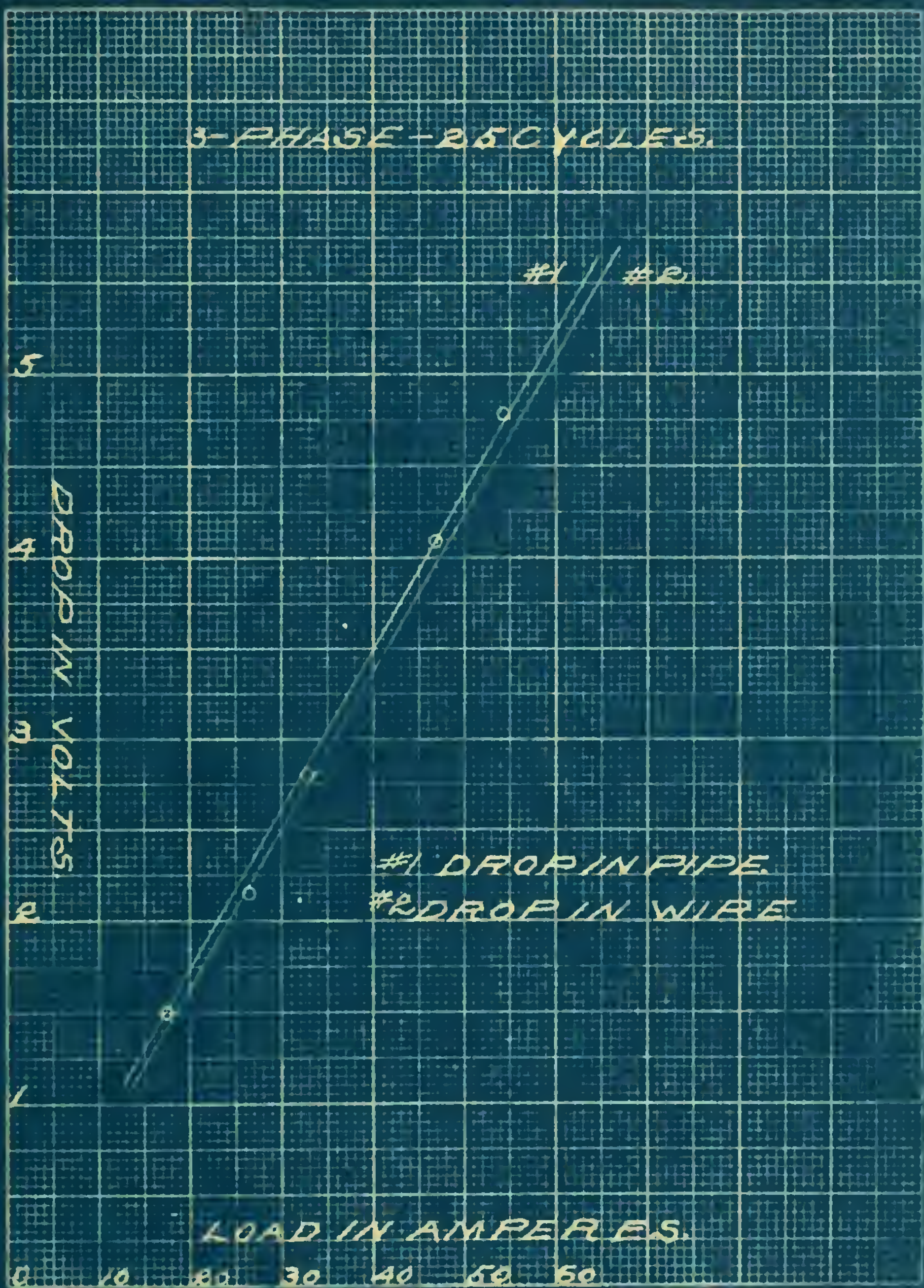
| 60 cycles. | | | 55 cycles. | | | 50 cycles. | | |
|---|---|---|---|---|---|---|---|---|
| Amp. | K.W. | Volts. | Amp. | K.W. | Volts. | Amp. | K. W. | Volts. |
| I7.8 | I.55 | I.35 | I8. | I.6 | I,54 | I7.4 | I.55 | I.52 |
| 25. | 2.25 | 2. | 25.8 | 2.4 | 2.I2 | 25.8 | 2.3I | 2.08 |
| 33. | 3.I | 2.84 | 33.8 | 3.3 | 2.84 | 33. | 3.06 | 2.8 |
| 40. | 3.8 | 3.55 | 45.7 | 4.3 | 4.05 | 40.5 | 3.7 | 3.42 |
| | | 4.24 | | | | | 4.3I | |
| 47.2 | 4.53 | 4.24 | 5I.5 | 4.7 | 4.75 | 47.5 | | 4.I3 |
| | | | | | | | 5. | |
| | | | | | | 54. | | 4.9 |

| 30 cycles. | | | 25 cycles. | | |
|---|---|---|---|---|---|
| Amp. | K .W. | Volts. | Amp. | K .W. | Volts. |
| I7.4 | I.55 | I.52 | I7.4 | I.55 | I.5 |
| 25.5 | 2.32 | 2.09 | 25.4 | 2.3I | 2.04 |
| 33. | 3.05 | 2.78 | 33. | 3.05 | 2.8 |
| 40. | 3.68 | 3.42 | 40. | 3.7 | 3.4I |
| 46.8 | 4.27 | 4.06 | 47. | 4.3 | 4.08 |
| | | | 54. | 5. | 4.8 |

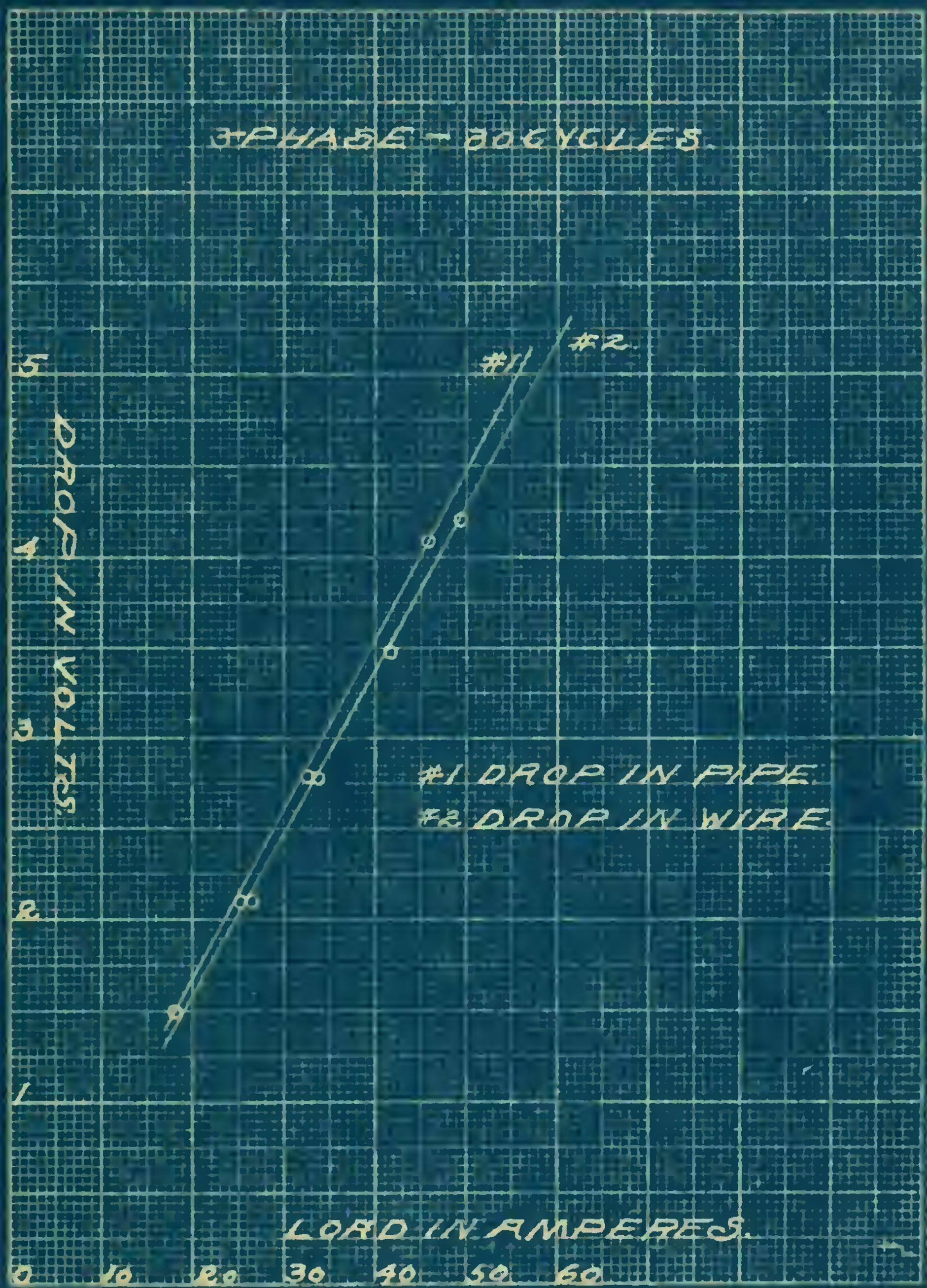
Three-phase Data. Wire out of the pipes.

| 60 cycles. | | | 55 cycles. | | | 50 cycles. | | |
|---|---|---|---|---|---|---|---|---|
| Amp. | K . W. | Volts. | Amp. | K.W. | Volts. | Amp. | K.w. | Volts. |
| I8. | I.6 | I.38 | I8. | I.6 | I.46 | I2.6 | I.65 | I.28 |
| 26. | 2.38 | 2. | 26.5 | 2.4 | 2.I | 25.7 | 2.4 | 2. |
| 33.8 | 3.I5 | 2.6 | 34. | 3.22 | 2.7 | 33.2 | 3.24 | 2.6 |
| 42. | 3.92 | 3.4 | 42. | 4. | 3.38 | 40.6 | 3.97 | 3.2 |
| 49.5 | 4.75 | 4.I2 | 49. | 4.7 | 4.I5 | 47.8 | 4.7 | 3.9 |
| 56.2 | 5.37 | 4.82 | 53.2 | 5.22 | 4.55 | 55.2 | 5.45 | 4.64 |

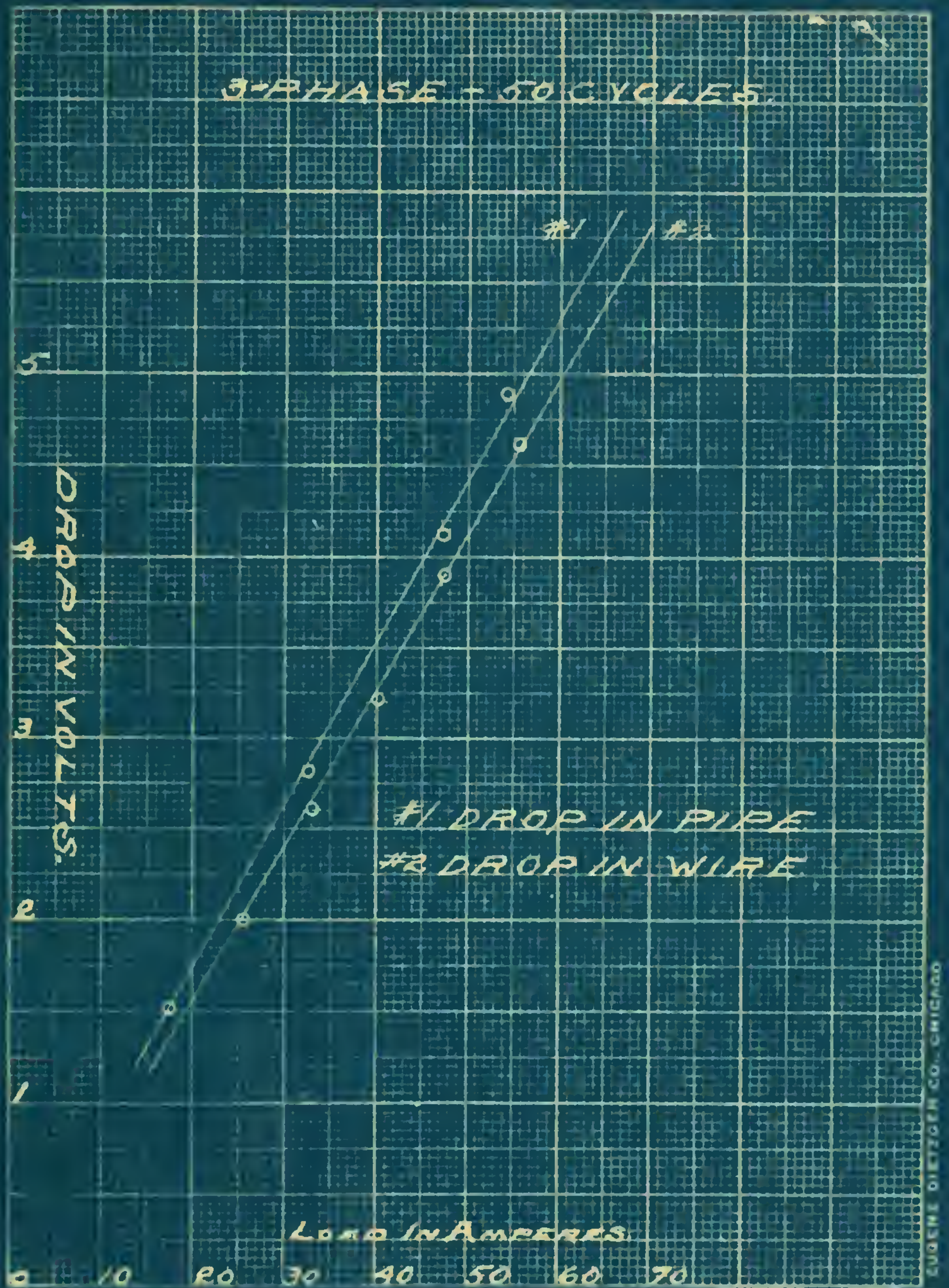
| 30 cycles. | | | 25 cycles. | | |
|---|---|---|---|---|---|
| Amp. | K . W | Volts. | Amp. | K . W . | Volts. |
| I7.8 | I.6 | I.5 | I8. | I.6 | I.5 |
| 26.6 | 2.4 | 2.I | 26.2 | 2.4 | 2.I4 |
| 34. | 3.2 | 2.78 | 34. | 3.2 | 2.78 |
| 42. | 3.9 | 3.48 | | | |
| 49.2 | 4.7 | 4.2 | | | |
| 57.3 | 5.52 | 5 | | | |

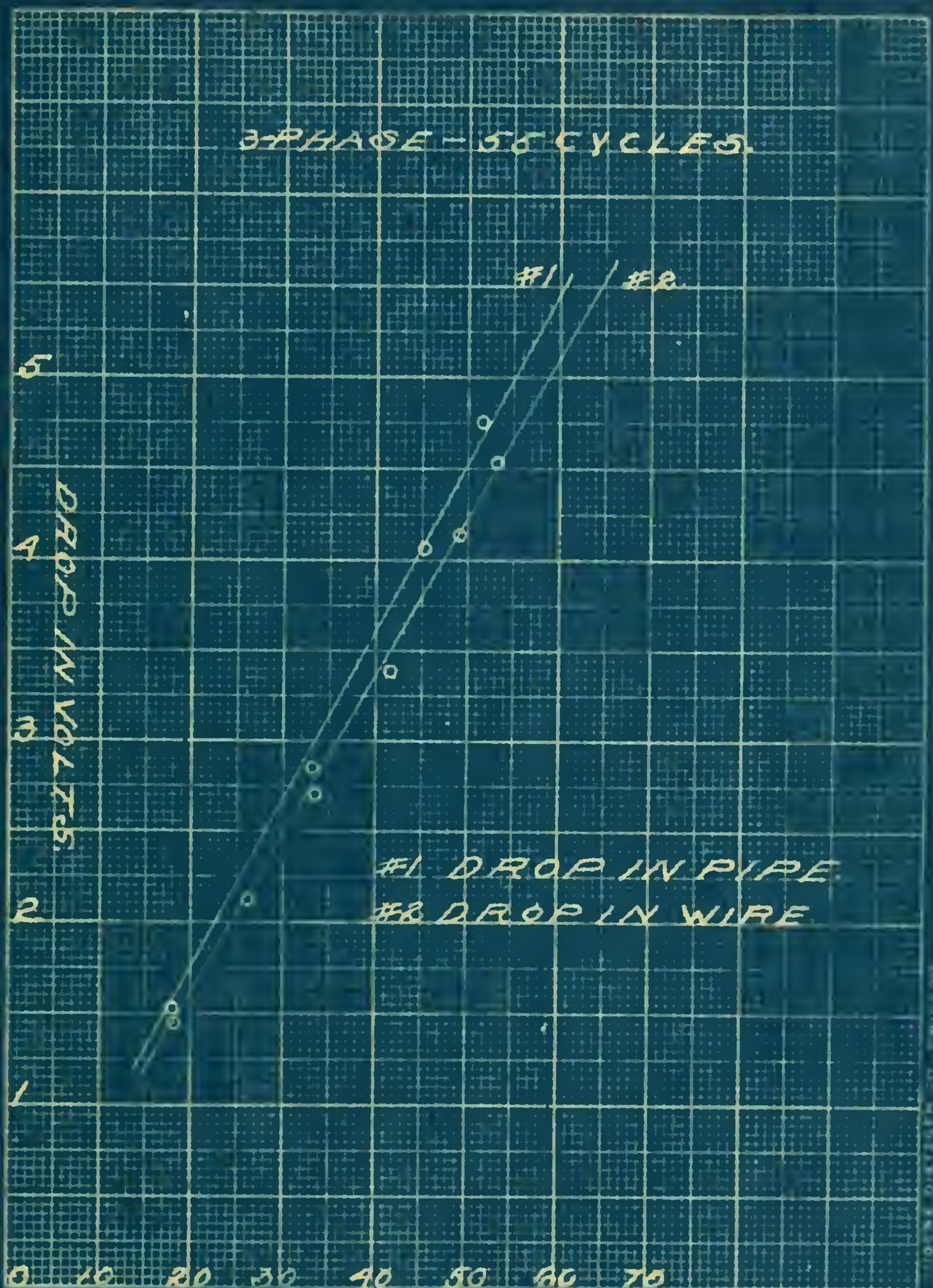


3-PHASE-25 CYCLES.
#1
#2
DROP IN VOLTS
5
4
3
2
1
#1 DROP IN PIPE.
#2 DROP IN WIRE
LOAD IN AMPERES.
0
10
20
30
40
50
60

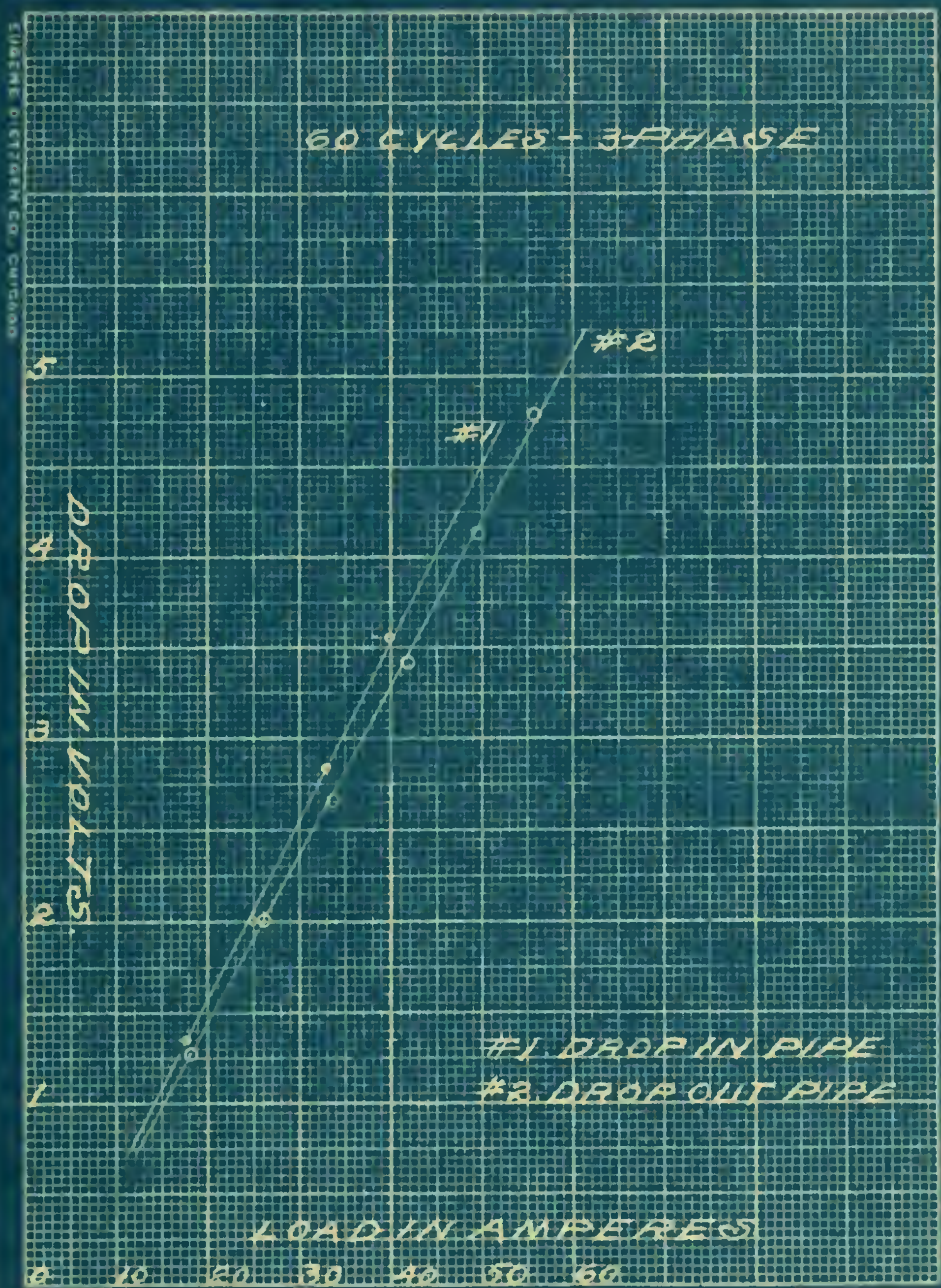


3 PHASE - 30 CYCLES.
#1
#2.
DROP IN VOLTS.
5
4
3
2
1
#1 DROP IN PIPE.
#2 DROP IN WIRE.
LOAD IN AMPERES.
0
10
20
30
40
50
60


3-PHASE – 60 CYCLES
#1
#2
DROP IN VOLTS.
5
4
3
2
1
0
#1 DROP IN PIPE
#2 DROP IN WIRE
LOAD IN AMPERES
10
20
30
40
50
60
70
EUGENE DIETZGEN CO. CHICAGO



3-PHASE — 50 CYCLES
#1
#2
DROP IN VOLTS
5
4
3
2
1
#1 DROP IN PIPE
#2 DROP IN WIRE
0
10
20
30
40
50
60
70


60 CYCLES - 3 PHASE
#2
#1
DROP IN VOLTS
5
4
3
2
1
#1 DROP IN PIPE
#2 DROP OUT PIPE
LOAD IN AMPERES
0
10
20
30
40
50
60
EUGENE DIETZGEN CO. CHICAGO

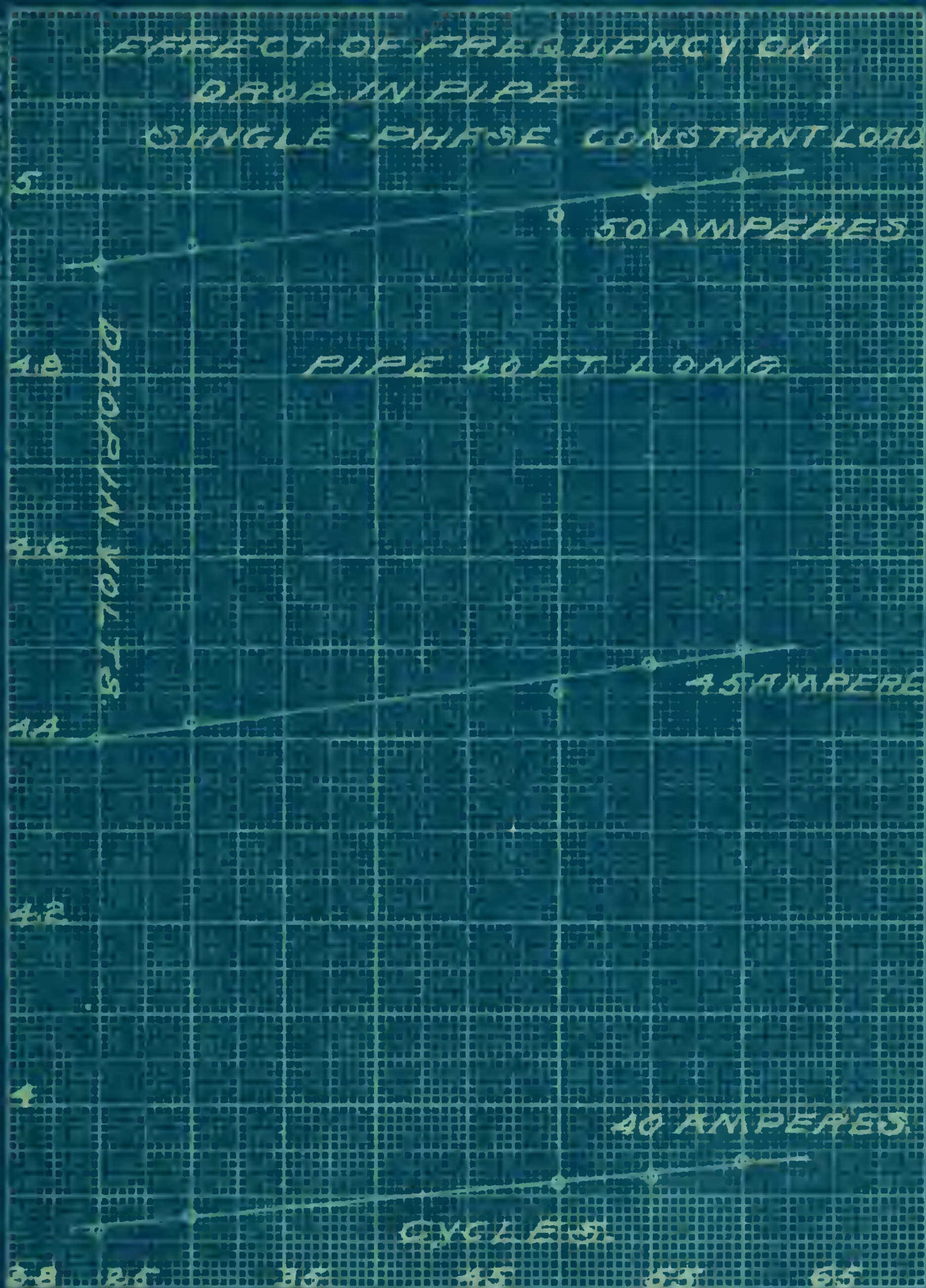
EFFECT OF FREQUENCY ON LINE DROP WITH CONSTANT LOAD.

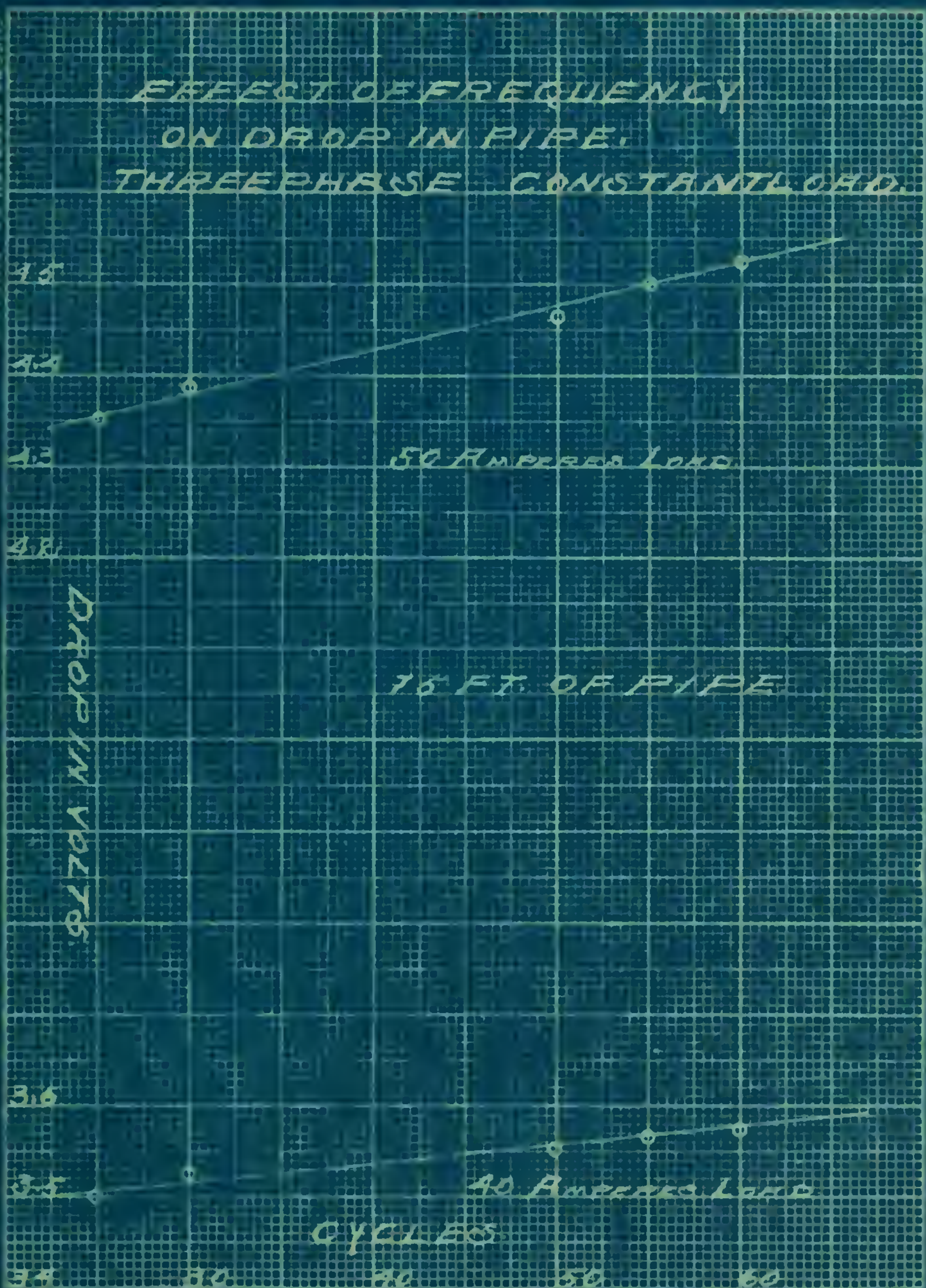
Single- Phase.

| | .40 Amperes. | 45 Amperes. | 50 Amperes. |
|---|---|---|---|
| Cycles. | Volts. | Volts. | Volts. |
| 25 | 3.86 | 4.4 | 4.92 |
| 30 | 3.88 | 4.42 | 4.94 |
| 50 | 3.9I | 4.45 | 4.97 |
| 55 | 3.92 | 4.48 | 5. |
| 60 | 3.94 | 4.5 | 5.02 |

Three- Phase.

| | 40 Amperes. | 50 amperes. |
|---|---|---|
| Cycles. | Volts. | Volts. |
| 25 | 3.5 | 4.35 |
| 30 | 3.53 | 4.4 |
| 50 | 3.55 | 4.45 |
| 55 | 3.57 | 4.5 |
| 60 | 3.58 | 4.52 |


EFFECT OF FREQUENCY ON
DROP IN PIPE
SINGLE-PHASE CONSTANT LOAD
50 AMPERES.
PIPE 40 FT. LONG
45 AMPERES
40 AMPERES.
DROP IN VOLTS.
CYCLES.
5
4.8
4.6
4.4
4.2
4
3.8
25
35
45
55
65


EFFECT OF FREQUENCY
ON DROP IN PIPE.
THREEPHASE CONSTANT LOAD.
4.5
4.4
4.3
50 Amperes Load
DROP IN VOLTS
75 FT. OF PIPE
3.6
3.5
40 Amperes Load
CYCLES
30
40
50
60

## CALIBRATION OF INSTRUMENTS.

### Weston Wattmeter.
#I79I

WATTS.

| True | Indicated |
|---|---|
| I | I |
| 2 | 2.02 |
| 3 | 3.0I |
| 4 | 3.98 |
| 5 | 5.04 |
| 6 | 6.02 |
| 7 | 6.98 |
| 8 | 8.04 |
| 9 | 9.04 |
| IO | IO.08 |
| II | II.07 |

### THOMSON A. C. AMMETER.
#705II

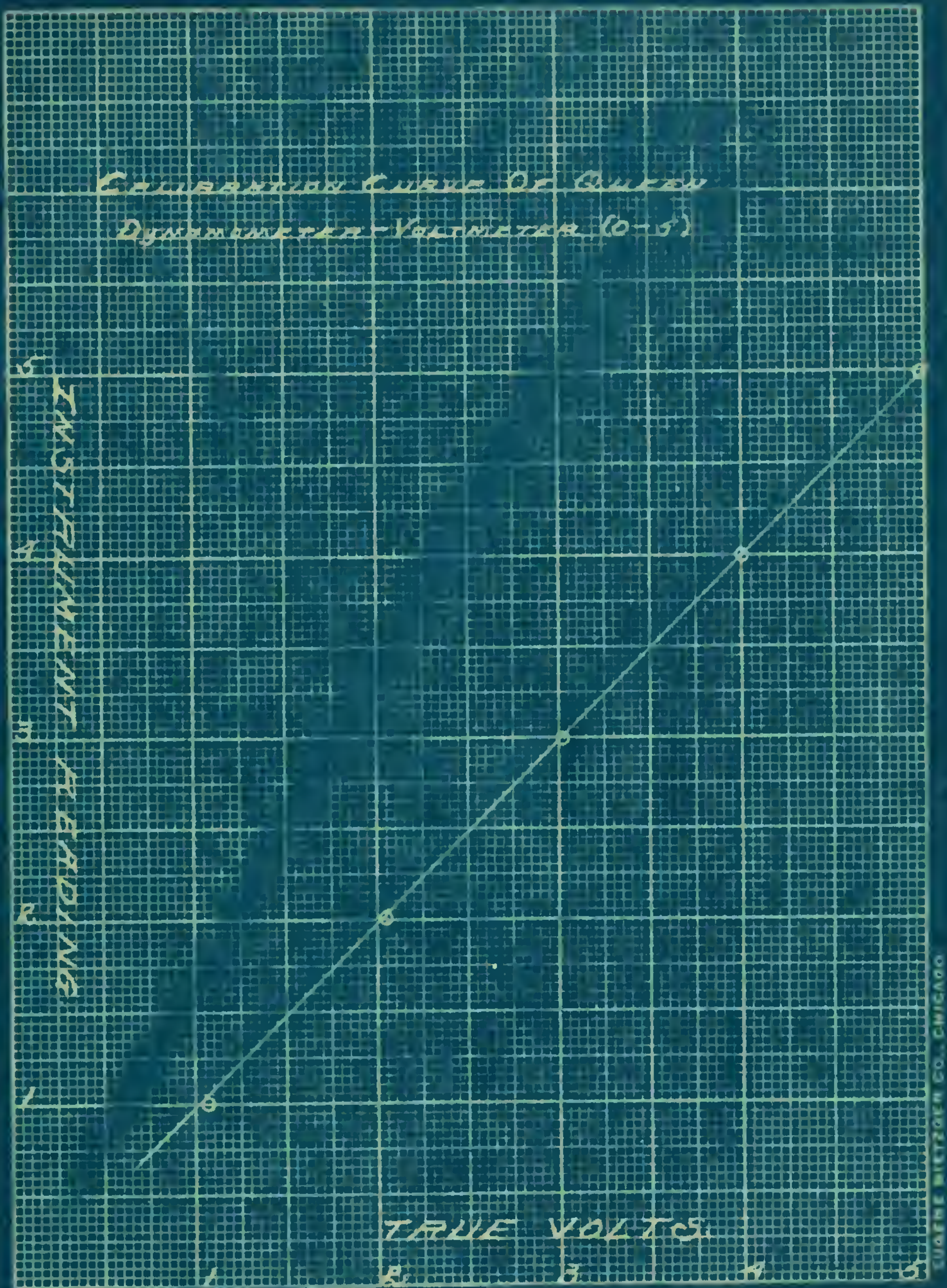
AMPERES.

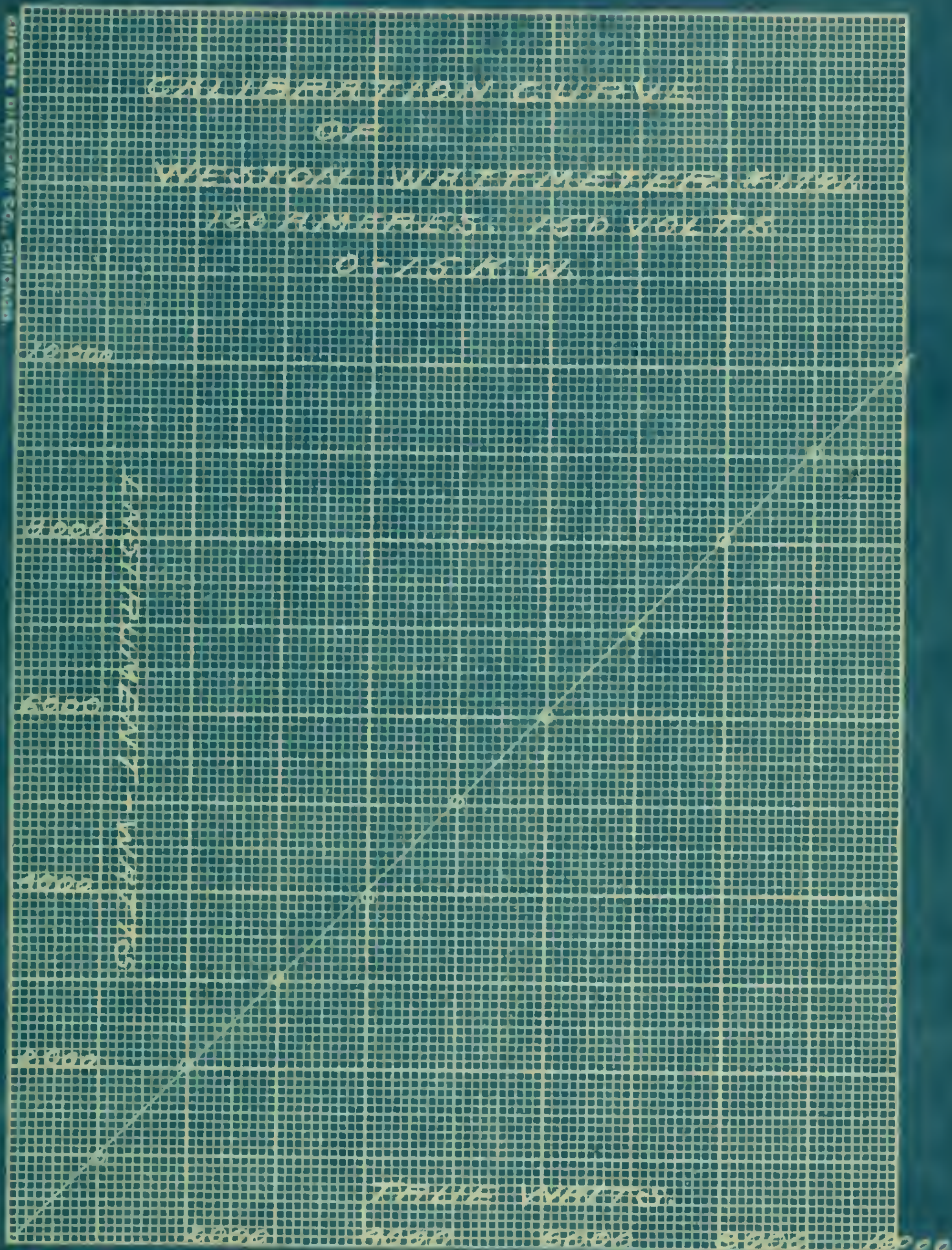
| True | Indicated. |
|---|---|
| IO. | IO |
| I7. | I5 |
| 2I.5 | 20 |
| 26.5 | 25 |
| 3I. | 30 |
| 36.8 | 35 |
| 4I. | 40 |
| 46. | 45 |
| 50.2 | 50 |
| 55. | 55 |
| 60. | 60 |

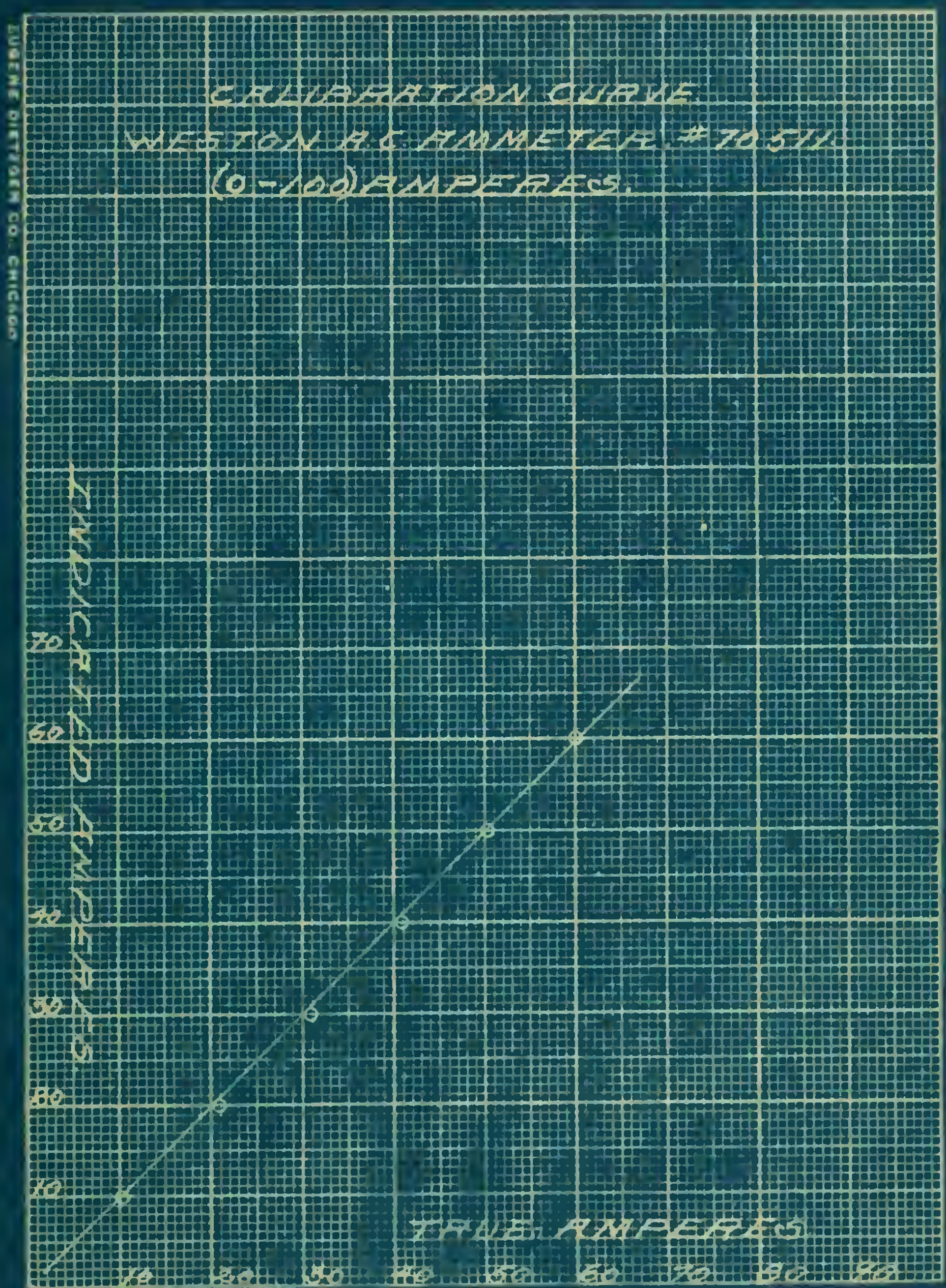
### QUEEN ELECTRODYNAMOMETER. (0-5)

VOLTS

| True | Indicated. |
|---|---|
| I. | .98 |
| I.5 | I.47 |
| 2. | I.98 |
| 2.5 | 2.48 |
| 3. | 2.99 |
| 3.5 | 3.5 |
| 4. | 4. |
| 4.5 | 4.5 |


Calibration Curve of Queen
Dynamometer-Voltmeter (0-5)
Instrument Reading
True Volts.
1
2
3
4
5
1
2
3
4
5
EUGENE DIETZGEN CO., CHICAGO


CALIBRATION CURVE
OF
WESTON WATTMETER
100 AMPERES. 150 VOLTS
0-15 K.W.
10000
8000
6000
4000
2000
TRUE WATTS.
2000
4000
6000
8000
10000


CALIBRATION CURVE
WESTON A.C. AMMETER #70511
(0-100) AMPERES.
INDICATED AMPERES
TRUE AMPERES
EUGENE DIETZGEN CO. CHICAGO

Explanation of data and curves.

Curves were platted from the data obtained to show graphically the difference between the drop over the wire when in the conduit and when outside of it.

The curves on pages ten to fourteen inclusive were platted from data taken with single-phase currenta Curve #I.being the drop over the wire in the pipe and curve #2 showing the drop over the wire when the conduit was not used. In the same way the curves on pages twenty to twenty-four were platted from the data taken with three-phase current.

The data on page twenty-five showing the effect of frequency on line drop was taken from the curves of variable load. From this data the curves on pages twenty-six and twenty-seven were platted.

The instruments used were carefully and accurately calibrated and curves platted from the data obtained and included in this paper on pages twenty)Nine to thirty-one inclusive.

## DISCUSSION.

By a comparision of the data and the curves previously given it can be seen that the iron conduit has a very marked effect upon the difference of potential over the wire, increasing it very noticably.

This increase in apparent resistance would be too small in value to be read on the average central station instrument. It is even very small when compared with the ohmic resistance of the wire.

From the data and curves of the single and three-phase currents, the authors find that the self-induction due to the use of the iron conduit has a greater effect for single phase currents. With the three-phase current and three wires in the conduit the fields causes by the current in the separate conductors would oppose each other. Since the currents are not in the same phase and therefore do not reach a maximum at the same time their fieldsneutralizing each other cutting down the self-induction.

The effect of different cyclic speeds was compare and it was found that the effect of self-induction increased directly as the frequency . The effect also increased directly as the load.

The same length of wire in the conduit was used in each case and the temperature at which the reading were taken

was kept as uniform as possible.

The wire used is the smallest wire found in construction work and the most available for this investigatiom. It furnishes a sample of what the effect would be if larger wire were used and a proportionately larger current.

With a load of fifteen amperes which is about the normal load for number fourteen wire on covered work the invreased load at sixty cycles single phase is about one tenth of a volt. The ohmic drop at this load was one and two tenth volts making the drop due to self-induction one twelfth of the ohmic drop.

The effect of self-induction would increase directly with the length of the iron conduit used, and one tenth of a volt for seventy five feet would mean .133, volts per hundred feet or 1.33 volts per thousand feet. With of fifteen amperes and sixty cycles with three phase currents the difference in voltage was .08 for seventy five feet of wire. This made the inductive drop on fifteenth of the ohmic drop. The drop per hundred feet would be .106 volts and per thousand feet of wire in the conduit would be 1.06 volts.

The induction of the wire in the conduit would be increased of where there are a number of circuits different wires of differnt phases put together. To avoid this it is wise to see that wires of the same phase are put in the same pipe and thus cut down the

effect of induction to a minimun. This is aespecially true in the wiring of large buildings.

If the wire is wound together as tightly as possib;e the induction will be reduced as well as the capacityof a pipe increased. With concentric wires the effect of self-induction will be reduced to zero. The induction in the wire besides caus~~e~~ing in increase drop in p~~r~~otential would a lso cause a large amount of heating of the iron which might reach dangerous limits if not reduced.

FINIS.